A Framework for Analyzing the Impact of Technology Transitions on USA Regulated Telecom Services - Particularly Transition from Copper to Fiber

Notes to the FCC Technology Transition Task force (Jan. 15, 2014)-GN Doc13-5, 12-353, 11-60

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At the FCC's Open Meeting on December 12, 2013, the Commission heard a status update on the Technology Transition Task Force's work towards making near-term recommendations related to the Commission's expectations and role in the IP transition. The Acting General Counsel, Jonathan Sallet, stated the general principles (see Fig.1) guiding the initiative with the immediate goal "to understand the impact of technology transitions on consumers through diverse experiments and open data initiatives". The main "technology neutral" policy guiding principles are: Public safety, Universal access, Competition, and Consumer protection. The FCC's Chief Technology Officer, Prof. Henning Schulzrinne, offered a three-layer architectural model consisting of Application, Transport and Network, and Physical layers (see Fig. 1) which identifies the different layers where technology transitions is taking place.

The regulatory requirements underpinning the values stated by the Task Force can be extracted, see Table 1, from the FCC's published documents. Public Safety, Competition, and Consumer protection are goals 6, 4 and 3 of the FCC Strategic Plan 2012-1016, and the Universal Service is defined in the FCC Universal Service Fund/ICC Transformation report and Order and Further Rulemaking (November 2011), and goal 1 of the FCC Strategic Plan.

This note uses the Task Force's model to analyze the impact of some technology transitions in the access network on the services delivered to consumers over the public network. The particular technology transitions analyzed are: from wireline to wireless physical layer, transition in the Customer Premises Equipment (CPE) from analog voice service to CPE with Transport and Network IP layer supporting digital voice (VoIP) service, transition in the Central Office equipment from digital TDM voice switching to VoIP routing, and finally the technology transition from copper twisted-pair to optical fiber in the physical layer.

In general, the driver for a technology transition in a functioning marketplace can be one of many that might benefit one or more market players. The drivers can be: new profitable service, new revenue stream, cost reduction, competition, regulation…etc. However, in the case of a non-functioning market, where competitive market forces fail to deliver the services to the citizen, regulatory intervention might be required.

One driver for a technology transition can be to offer incrementally higher bandwidth services over the same infrastructure. Figure 1 shows the bandwidths of the different electronic communication services starting from 4 kHz for analog telephony to 24 Gbps for broadcast Super-Hi-Vision television. Figure 1 also shows the capacity of the different transmission physical media and the distances over which this capacity can be achieved. The important physical characteristics of the physical layer are: bandwidth, attenuation (which determines reach), and power handling capacity (which determines possibility of remote powering the CPE for high service availability). In general, the required power to operate the electronic equipment will increase with increased service bandwidth and CPE functionality.

Of course, each transmission medium in the physical layer can only support services suitable for that medium. For instance, mobile services can only be offered over wireless transmission, while wireline (guiding medium) can only support services at a fixed location. However, very high bandwidth services are best supported over guiding medium; such as optical fiber (more than 30,000 GHz bandwidth), so a transition from wireline only to wireless only will offer mobile services, but will not support future high bandwidth applications and services due to the limited wireless spectrum/bandwidth. Of course, wireless and wireline connections can complement each other to offer very high bandwidth and high service availability over wireline connection, and mobile services over wireless connections.

In general, a transition in one layer might require transition in another layer. For example, services requiring more than 30 Mbps/customer over distances of 3 km can only occur if the physical layer supports this transmission rate per customer over such distances. For example, an all-copper twisted-pair infrastructure can provide maximum capacity of 20 Mbps up to 1 km, so a transition from an all-copper access to a network containing fiber network (FTTH, FTTN/C, HFC) must occur to deliver the 30 Mbps service.

The FCC model also shows that the transitions to IP technologies actually occur at the Transport/Network layer. Two different types of technology transitions to IP can be considered: the first is from an existing time-based network switching technology (Time-Division-Multiplexing TDM, Circuit-Switched) to IP packet routing technology; the second type of transition is from CPE without IP to CPE with IP, for example a transition from analog POTS technology to VoIP router at CP.

The above examples illustrate the usefulness of the model as a framework to identify and assess the impact of technology transitions on services currently regulated by the FCC. To elaborate on the model usefulness, Figure 2 shows technologies and architecture of a national telecom network to deliver communication services to end users over different electronic communication networks. Figure 2 shows the typical CPEs (phone, TV, PC, radio..) and mobile equipment used to support the services listed in Fig. 1. The CPE is connected to a Public Network Operator through the access network using any of the physical technologies. Figure 2 also shows the carriers' networks spanning a country consisting of applications, transport and network, and physical layers. This network is used by the carrier to transport cost effectively the signal, directly or through another carrier, to another end-user who can be a residential customer or a public service; such as police, ambulance, fire service…etc. Clearly, two regulatory interconnections/interfaces that can be impacted by technology transitions: the customer-carrier interconnection and the carrier-carrier interconnection.

Figure 2 also shows that power sources are required at different locations to operate the communication system. Of course, mobile or portable equipment normally rely on batteries that need to be recharged from a mains supply. The importance of CPE powering was learnt through the hard lessons of "natural experiments" super storm Sandy in 2012, and the derecho in Midwest and Mid-Atlantic in 2011 when power outages lasted several days and thousands of homes were unable to access 911 emergency services when most needed.

A technology transition in the carrier-carrier connection can occur; for instance from TDM or Circuit Switching to IP routing. This might impact the Inter-Carrier Compensation (ICC) regulation, the bill and quality of services offered to the end consumer. The impact assessment of this transition is not covered by this note.

The remainder of this note assesses the impact of technology transitions in the customer-carrier interconnection on universal services availability, network reliability and resilience. The Universal Service order (November 2011) states that voice service is a Universal Service in the USA, and access to emergency services through 911 is a regulatory requirement. The order also requires universal availability of modern networks capable of providing voice and broadband service to homes, businesses, and community anchor institutions. In addition, goal 6: Public Safety and Homeland Security of FCC Strategic Plan requires the availability of reliable and rapidly restorable critical communication infrastructure.

The transition of the CPE from analog voice telephony to digital voice over IP (VoIP) in the application, transport and network layers will impact the regulatory requirements. This transition, driven by low telephone bill, can lead to a considerable increase in CPE power consumption, causing a change in the CPE powering architecture from centralized powering to local powering which might rely on battery backup. Table 2 compares the different architectures for powering the access network. The current VoIP modems consume at least 1-W in the idle/quiescent state (ON-hook), compared to less than 1-mW in consumed by an analog telephone in the same state. Obviously, VoIP telephone modems (CPE) must rely on local powering with battery backup in case of power outage. This transition from analog telephone CPE service with centralized powering (99.999% availability at low cost) to digital VoIP CPE with local powering with battery backup will result in lower service availability and lower network reliability and slower restorable critical communication infrastructure.

Historically the analog voice signal over a POTS connection is converted by the CO equipment to a digital signal which is then routed using TDM switches. Hence, a transition from voice over TDM to VoIP in the Transport and Network layer at the CO can occur, while maintaining the analog telephone CPE with centralized powering architecture. This transition (that might be driven by carrier's cost reduction) offers high service availability, high network reliability and rapidly restorable critical communication infrastructure.

Another transition is from wireline to a wireless connection in the physical layer, which will change the telephone powering architecture from centralized powering to local powering with battery backup in case of power outage at CP. This transition will result in lower service availability and lower network reliability and slower restorable critical communication infrastructure impacting negatively Public Safety and Homeland Security. Of course, having both wireline and wireless connections will provide two independent connections to the public network which improves Public Safety.

The final technology transition considered in this note is from a copper twisted-pair to an optical Fiber-to-the-Home (FTTH) physical layer. The driver for this transition might be offering multi-services of new very high bandwidth applications in addition to telephony, exploiting the future-proof optical fiber infrastructure of more than 30,000 GHz bandwidth, at low cost over distances of more than 10 km. However, the currently standardized FTTH GPON and EPON technologies can deliver gigabit services, but rely on battery backup at customer premises to maintain the "lifeline" telephone service in case of power failure. This is an expensive solution that offers lower availability than the 99.999% (five nines) which copper based networks delivers. To solve this problem, centralized optical powering over optical fiber can be used to support “lifeline” voice universal service without using copper links or battery backup. This way, high levels of universal service availability can be achieved at cost similar to that of copper systems. Dr. Salah Al-Chalabi has published in the last 18 months two papers in the IEEE Communications Magazine (Sept. 2011 and Aug. 2012) on optically powering the telephone over optical fiber titled:

- “Powering the telephone over optical links for high availability, low cost, and small carbon footprint”; S. A. Al-Chalabi, IEEE Communications Magazine, Sept. 2011, pp. 48-55.
- “Optically powered telephone system over optical fiber with high service availability and low risk of investment in FTTH infrastructure”; S.A. Al-Chalabi, IEEE Communications Magazine, Aug. 2012, pp. 102-109.

In the first paper Dr. Al-Chalabi shows that it is feasible to power the telephone at customer premises optically by sending optical power over the optical fiber connection. Very low power consumption optical communications systems must be used. The power consumption of a standard telephone apparatus in its different states is analyzed, and a simple mathematical model is developed and used to calculate the power required to operate the telephone for different states’ durations. Optical power levels transmitted over optical fiber are limited by nonlinear effects, and safety standards. Current standard GPON and EPON equipment can not be powered over optical fiber, and must use battery backup. A low cost telephone service with 24/7 availability over optical fiber provides the infrastructure to offer broadband and HDTV exploiting the more than 30,000 GHz capacity of the optical fiber.

In the second paper, Dr. S. A. Al-Chalabi states that optical communication systems can compete with traditional twisted-pair copper systems in delivering universal telephony. However, they must achieve the same levels of cost and availability, and must satisfy the same regulatory requirements. An innovative optical communications system that can meet these requirements is then described where part of the received optical power is converted to electrical power using photovoltaic cells and an energy storage device to drive the CPE. The reach of the system can be more than 10 km, which covers urban and rural areas in the USA. Delivering voice over fiber as a Universal Service at comparable cost with that of delivering it over copper removes the uncertainty in service takeup over fiber, and eliminates the investment risk in a FTTH infrastructure. Superfast broadband data and HDTV services can be added to this future-proof infrastructure, when requested by the customer, with much lower incremental cost than would be needed for copper-based systems. The proposed optical communication system consumes power comparable to telephone system over copper twisted pair connections.

The lowest cost upgrade strategy is to install the “lifeline” voice system as a foundation and add the superfast data and HDTV upgrades by posting low cost, standardized “plug-and-play” CPE that can be installed by the customer with the help of technical support over the “lifeline”. This optical, future-proof infrastructure of more than 30,000 GHz can then be exploited to deliver the very high bandwidth advanced services, which twisted pairs and coaxial cables can not deliver over distances of 10 km.

This transition from copper to optical fiber in the physical layer with centralized optical powering can support Universal Service telephony and offer high service availability and high network reliability and rapidly restorable critical communication infrastructure impacting positively on Public Safety and Homeland Security. The very high bandwidth of optical fiber (more than 30,000 GHz) connection provides the future-proof broadband network required by Connect America’s objective and by the USF/ICC Order (2011) to connect customers in urban and rural areas, and encourages competition and innovation. In addition, such low power consumption optical communication systems offer not only low-cost universal services, but also future-proof optical broadband local and environmentally-friendly communication network supporting the efforts of the FCC and USA government to reduce the power consumption and carbon footprint of the communications sector.

I hope that this note provides a framework that helps identifying certain technology transitions which the Technology Transition Task Force might want to address. One such area is technical standards for the regulatory “Demarcation Point” shown in Figure 2. Defining this regulatory point will determine where the Universal Service is provided. The traditional telephone apparatus and service are regulated as “voice grade access - CFR 47 Part 54 – Universal Service, and Part 68” and supported technical standard TIA 968. According to these standards, the telephone apparatus should consume less than 1 mW in the quiescent/idle state. However, currently standardized broadband and VoIP telephones consume more than 1 W in this idle state. It is, therefore, very important that the FCC should support and provide regulatory requirements to technical standards making bodies in the area of public communication networks. Technical standards supported by the FCC should cover not only the copper physical layer, but also other technologies such as FTTH and networks.

I will be very happy to provide the FCC more detailed information about possible low power optical technology which should provide uninterrupted access to emergency service over fiber at low cost. This should protect the citizen much better than currently standardized optical technologies for the access network, and provide a future-poof, high bandwidth infrastructure (more than 30,000 GHz) supporting universal services in urban and rural areas in the USA.

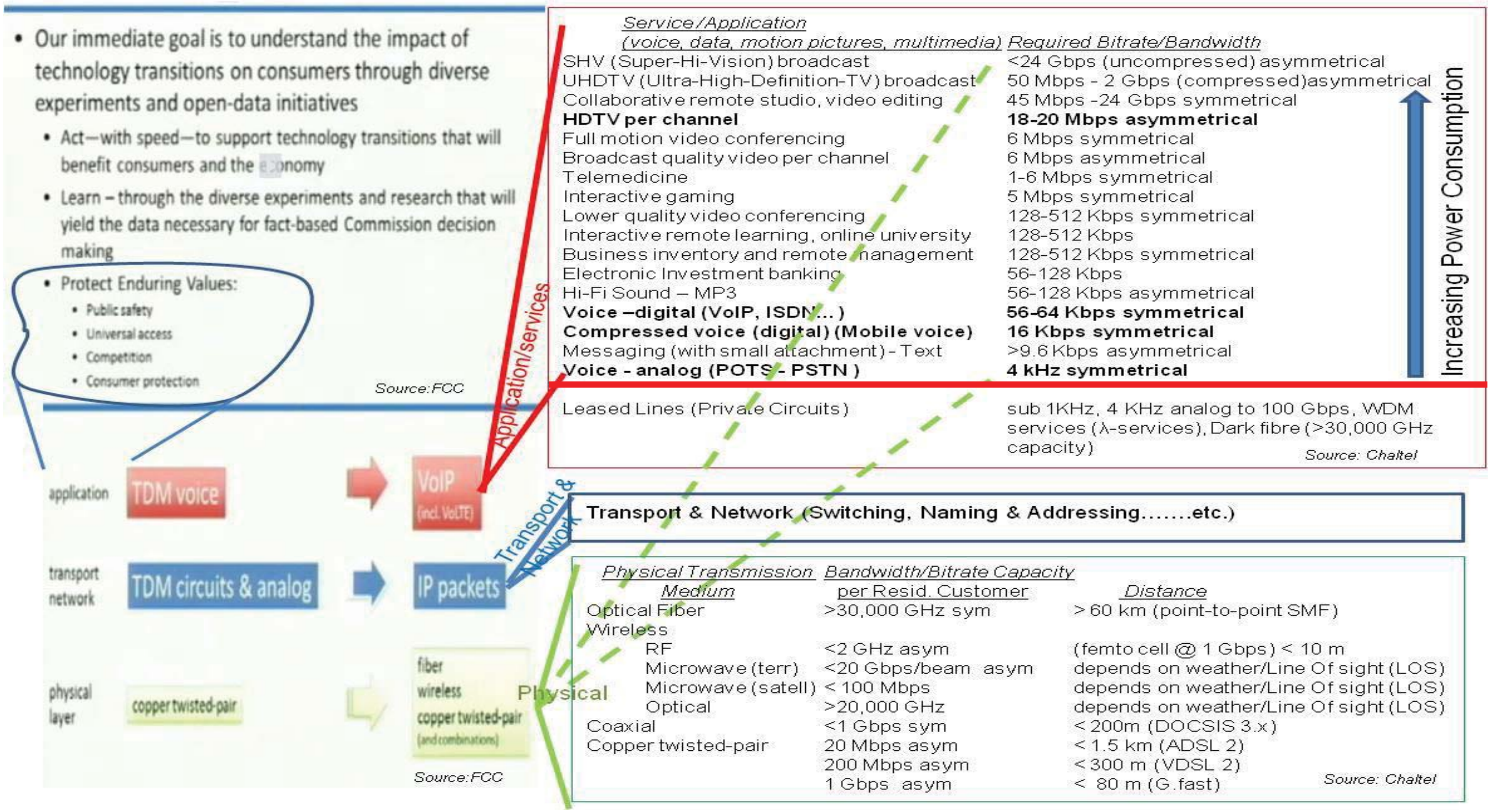

Figure 1: A Framework for Mapping the Impact of Technology Transitions of Different Communication Services, Transport and Network layer, and Physical Layer's Bandwidth and Capacity onto FCC Guiding Values and Strategic Objectives

Table 1: FCC Enduring Values and Objectives Impacted by Technology Transitions

USA - FCC document: **Universal Service Fund/ICC Transformation report and Order and Further Rulemaking (November 2011)**
The goals are: (1) preserve and advance universal availability of voice service; (2) ensure universal availability of modern networks capable of providing voice and broadband service to homes, businesses, and community anchor institutions; (3) ensure universal availability of modern networks capable of providing advanced mobile voice and broadband service; (4) ensure that rates for broadband services and rates for voice services are reasonably comparable in all regions of the nation; and (5) minimize the universal service contribution burden on consumers and businesses. Carriers that elect to receive Connect America Fund must provide broadband with actual speeds of at least 4 Mbps downstream and 1 Mbps upstream, with latency suitable for real-time applications and services such as VoIP, and with monthly usage capacity reasonably comparable to that of residential terrestrial fixed broadband offerings in urban areas. In addition, to ensure fairness for consumers across the country who pay into USF, we reduce existing support levels in any areas where a price cap company charges artificially low end-user voice rates. **Voice Service:** To promote technological neutrality while ensuring that our new approach does not result in lower quality offerings, we amend section 54.101 of the Commission rules to specify that the functionalities of eligible voice telephony services include voice grade access to the public switched network or its functional equivalent; minutes of use for local service provided at no additional charge to end users; toll limitation to qualifying low income consumers; and access to the emergency services 911 and enhanced 911 services to the extent the local government in an eligible carrier's service area has implemented 911 or enhanced 911 systems.
FCC document: **FCC 2012-2016 Strategic Plan**
Goal 1: Connect America *Objective 1.2*: Maximize availability of fixed and mobile broadband to all Americans and community anchor institutions, including in rural and insular areas and Tribal lands, while ensuring that universal service programs are efficient, effective, and impose no greater burden on consumers and businesses than necessary. **Goal 3: Protect and Empower Consumers** *Objective 3.2:* Act swiftly and consistently in the use of enforcement authority to protect consumers. Among the Commission's most important responsibilities is protecting and empowering consumers. As communications networks and technologies become increasingly complex and essential to Americans' everyday lives, the Commission must be a vigilant watchdog for the consumer…… The FCC will ensure that Commission proceedings take account of consumer interests, and that consumer protection and empowerment policies apply consistently and reasonably across technologies and bureaus at the FCC. We will continue to provide consumers with up-to-date, user-friendly advisories concerning their rights, responsibilities, service options, and information to make informed decisions.

Goal 4: Promote Innovation, Investment, and America's Global Competitiveness
Objective 4.3: Preserve the free and open Internet as a platform for economic growth, innovation, job-creation, and global competitiveness.
One of the most important features of the Internet is its openness. It uses free, publicly available standards that anyone can access and build to, and it treats all traffic that flows across the network in roughly the same way. … The FCC adopted Open Internet rules to ensure that the Internet remains a powerful platform for innovation and job creation; to empower consumers and entrepreneurs; to protect free expression; to promote competition; to increase certainty in the marketplace by providing greater predictability for all stakeholders regarding federal policy; and to spur investment in our nation's broadband networks……..

Goal 6: Public Safety and Homeland Security
Vision: *Promote the availability of reliable, interoperable, redundant, rapidly restorable critical communications infrastructures that are supportive of all required services*

Objective 6.1: **Promote access to effective communications services, including next generation services, in emergency situations across a range of platforms by public safety, health, defense, and other emergency personnel, as well as all consumers in need.**
The Commission continues to facilitate the deployment of 911 services and technologies and to pave the way for greater capabilities, including by helping define the system architecture and develop a transition plan to establish a digital, Internet Protocol (IP)-based foundation for the delivery of multimedia 9-1-1 "calls." 911 call centers could receive text, pictures and videos from members of the public, providing additional information to first responders as well as an additional means for persons who are injured, witness an accident or are disabled to contact a 911 dispatcher…..
Objective 6.2: **Evaluate and strengthen measures for protecting the nation's critical communications infrastructure and facilitate rapid restoration of the U.S. communications infrastructure and facilities after disruption by any cause, including cyberattacks.**
The FCC is committed to ensuring the public's safety through the reliability of our nation's communications networks, including during natural and manmade disasters. The Commission will provide leadership in the protection of the Nation's critical communications infrastructure, including working with public safety and stakeholders to maximize the availability, interoperability, and reliability of communications.

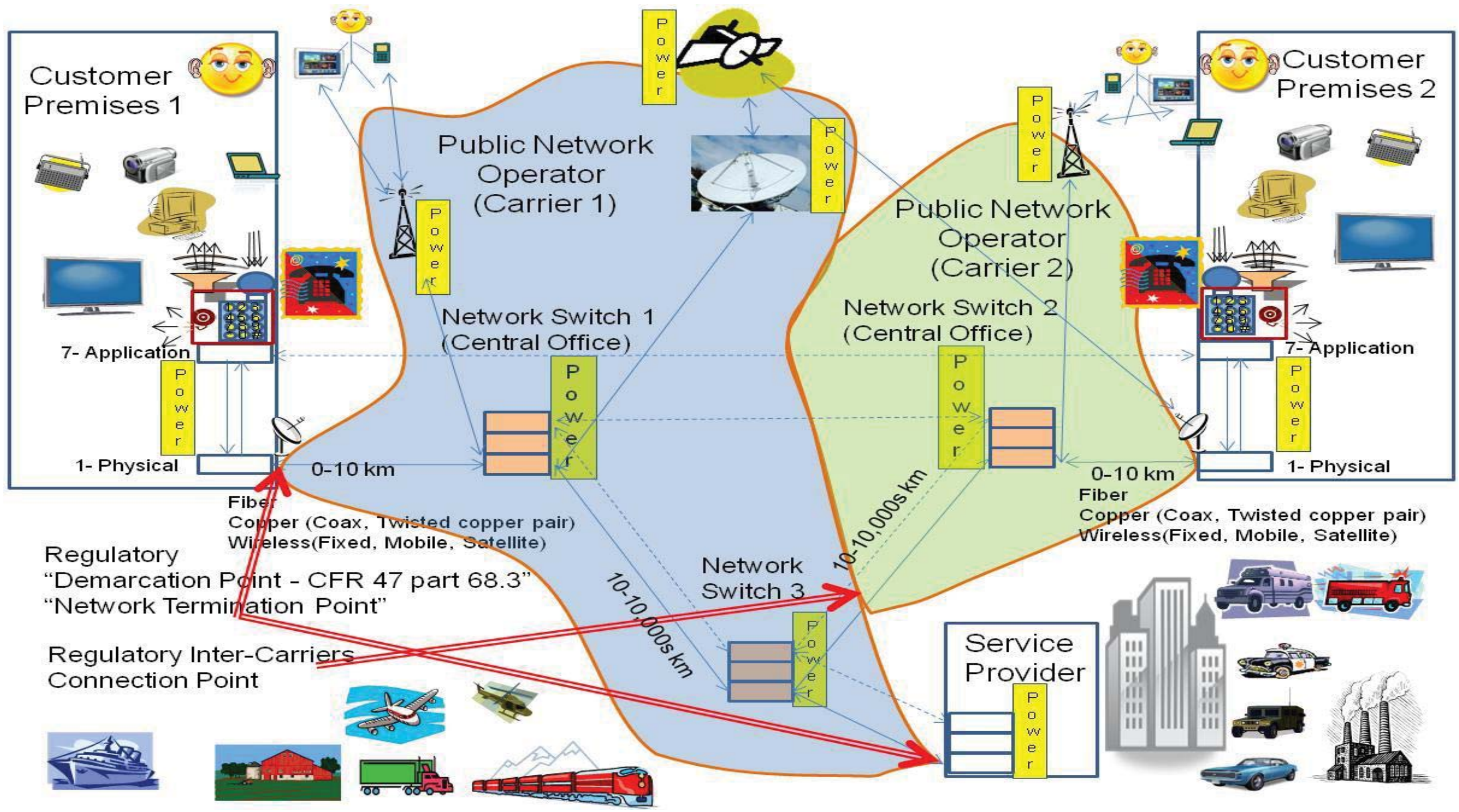

Figure 2: National and Global Telecommunication Network and Systems Architecture

Table 2: Standard Access Network Powering Architecture

Powering	Definition and main power source location	Back-up battery location	Resilience/ Restoration time	Cost	Physical Layer Technology & Architecture
local powering:	powering a telecommunications equipment by a (dedicated) power unit implemented at the CP.	CP (indoor or outdoor)	low/long	high	FTTH, Wireless (Wi-Fi, cellular, Wi-Max, Satellite set-top box, TV), CATV, VoIP (modem or Personal Computer)
reverse powering:	Power from the CP is provided to a Distribution Point (DP) outside the CP by means of a dedicated power copper line from each CP. The DP can serve one or several CPs.	DP or CP	Low/long	high	FTTC/B (evolving G.fast standard)
cluster powering:	remote powering of a cluster of equipment, in which the power source is located outside a telecommunications centre (CO).	Outdoors in - street cabinets or - underground manholes	medium/ medium	medium	FTTB, FTTC/N , CATV, wireless (base stations, satellite ground stations)
centralized powering:	remote powering in which the remote power source is located in a telecommunications centre (CO).	CO (a back-up generator can also be used with stored fuel)	very high/ short	low	Copper, FTTH (remote optical powering)

CP: Customer Premises

CPE: Customer Premises Equipment

CO: Central Office

DP: Distribution Point

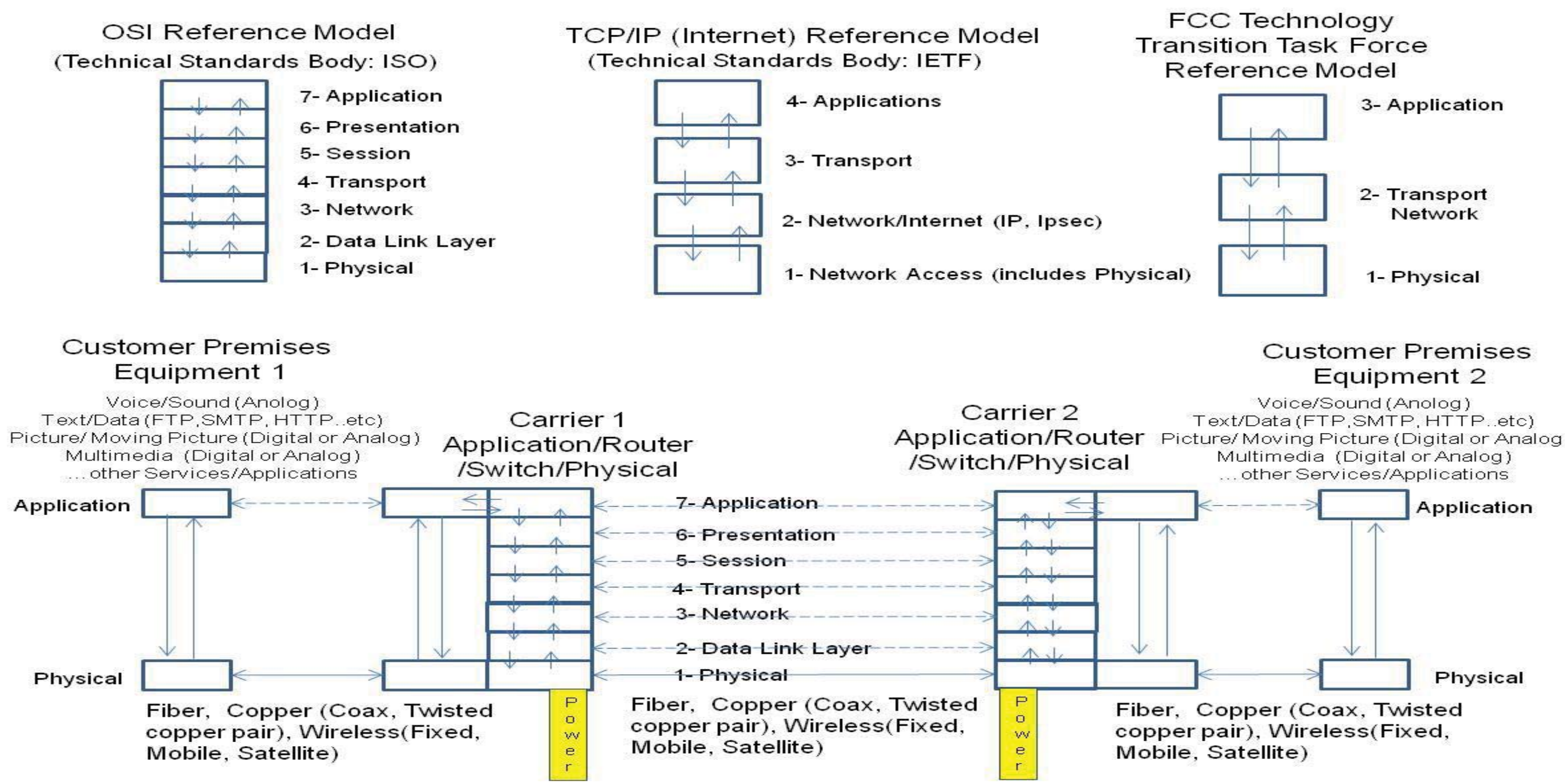

Figure 3: Top: Communication System Reference Model Architectures; Lower: Possible Implementation of a Networked Communication System with Analog or Digital Transmission between CPE and CO

Note: It is important to note that the above models are only used to help understand networked communication systems (especially digital systems or computers). Other models exist.